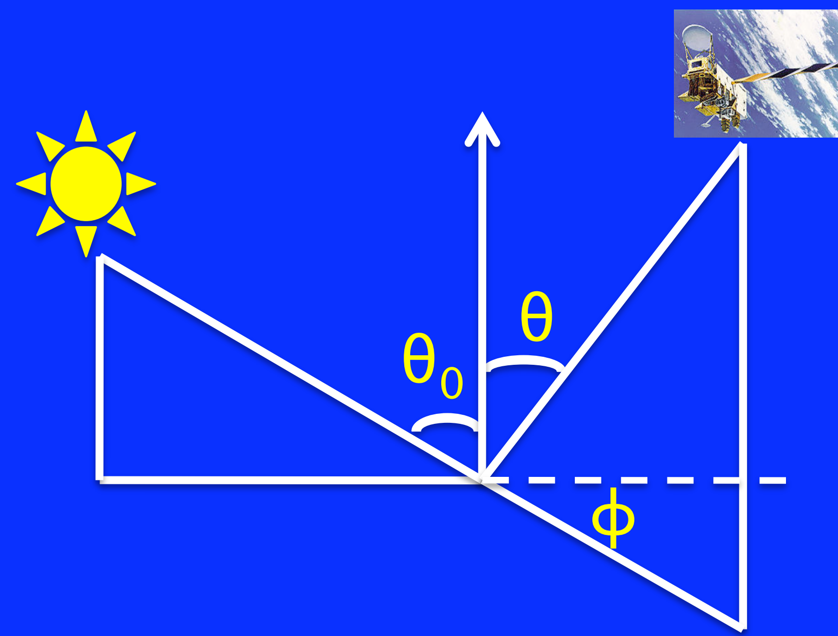
The road from radiance to flux: angular distribution model

- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type;
- Apply anisotropic factor to observed radiance to derive TOA flux;



$$R(\theta_0,\theta,\phi) = \frac{\pi \hat{I}(\theta_0,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} \hat{I}(\theta_0,\theta,\phi) cos\theta sin\theta d\theta d\phi} = \frac{\pi \hat{I}(\theta_0,\theta,\phi)}{\hat{F}(\theta_0)}$$

$$F(\theta_0) = \frac{\pi I_o(\theta_0,\theta,\phi)}{R(\theta_0,\theta,\phi)}$$

Predicted radiance vs. observed radiance

$$R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)} \qquad F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

$$F(\theta_0) = \frac{I_o(\theta_0, \theta, \phi)}{\hat{I}(\theta_0, \theta, \phi)} \hat{F}(\theta_0)$$

- Predicted radiances can be used to verify the accuracy of ADM;

Normalize predicted and observed radiance

Observed radiance:

$$I_j^o, \quad j = 1, \cdots, n$$

1°

Predicted radiance:

$$\hat{I}_j, \quad j = 1, \cdots, n$$

1°

$$\overline{I^o} = \frac{1}{n}\sum_{j=1}^{n} I_j^o \qquad \overline{\hat{I}} = \frac{1}{n}\sum_{j=1}^{n} \hat{I}_j$$

$$RMS = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(\frac{\hat{I}_j}{\overline{\hat{I}}} - \frac{I_j^o}{\overline{I^o}}\right)^2}$$

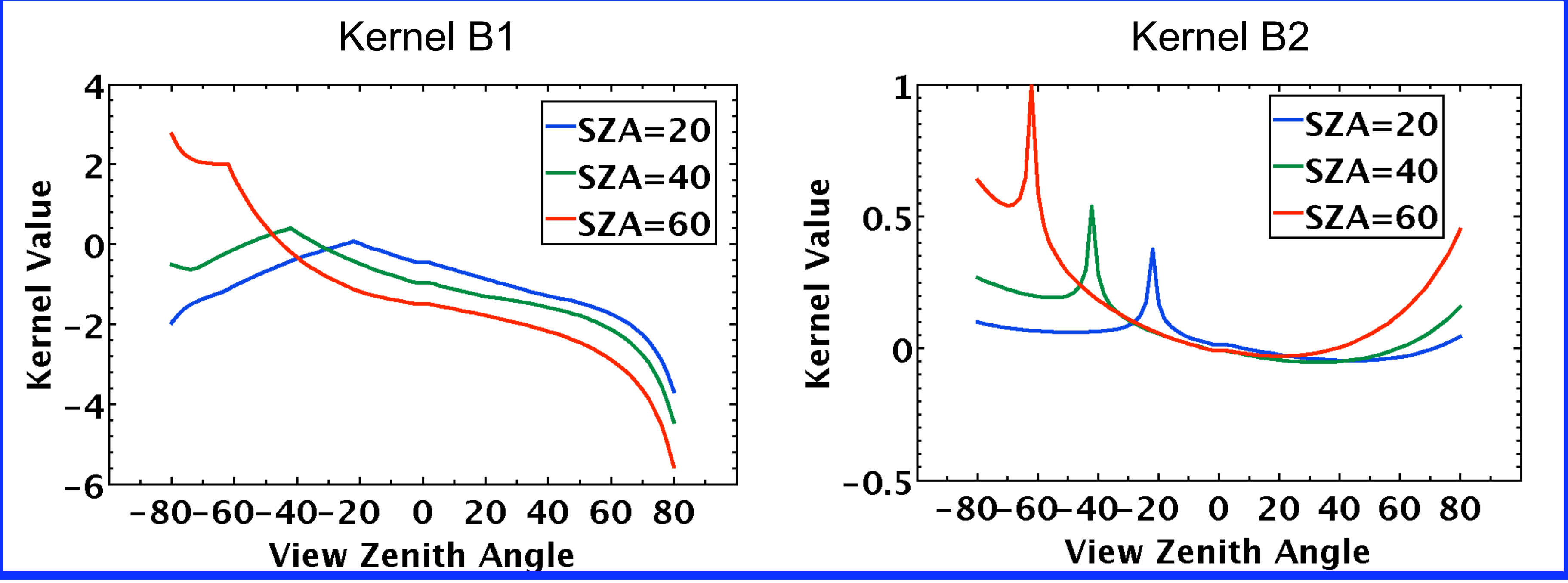
- RMS error between normalized predicted radiance and normalized observed radiance is closely related to the ADM error
- RMS error of 10% (20%) corresponds to flux RMS error of about 2~12 (4~15) Wm^{-2} over different scene types based upon theoretical simulations

SW angular distribution model over clear land: Modified RossLi

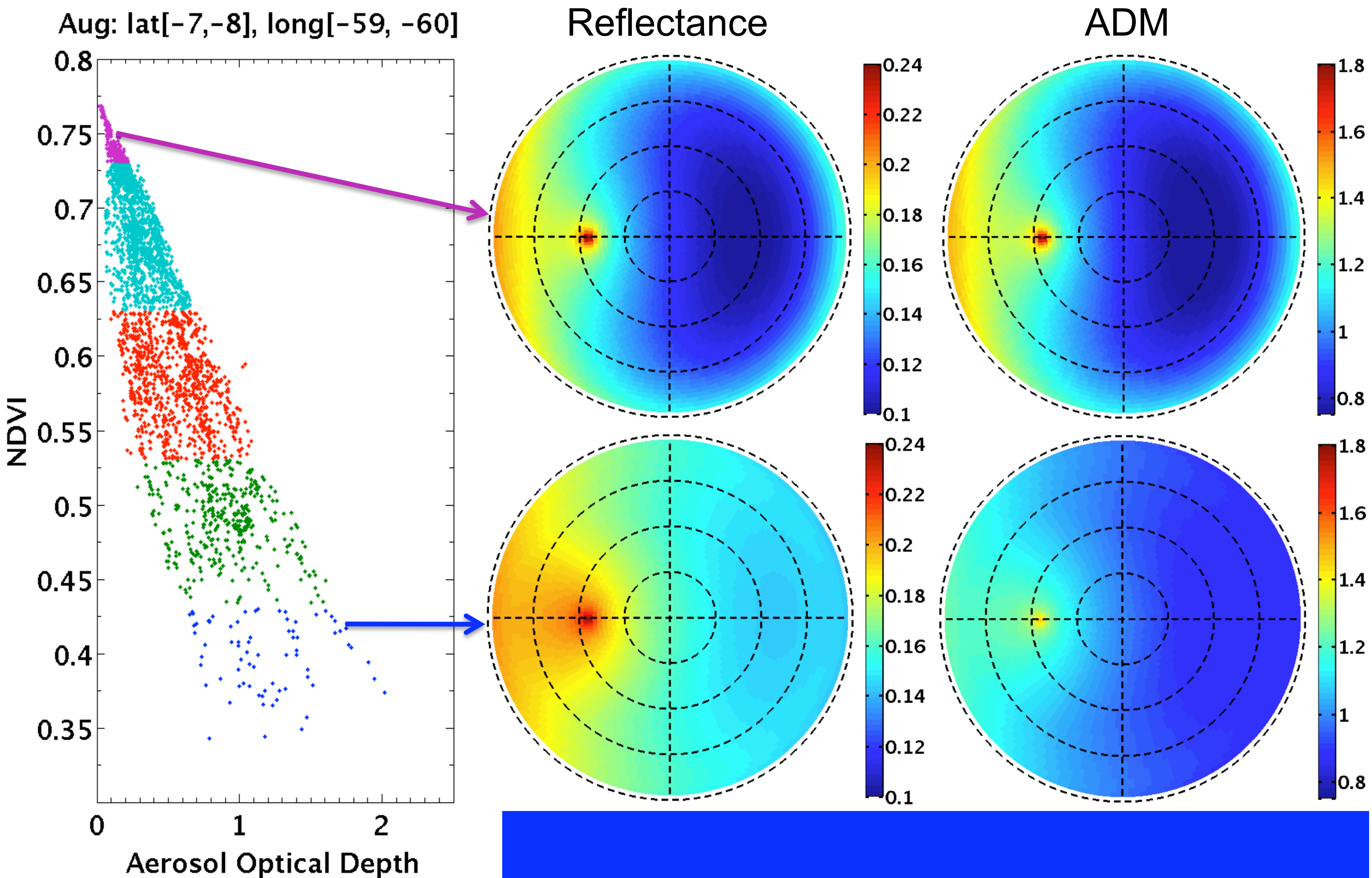
- Collect clear-sky reflectance over 1°X1° regions for every calendar month;
- Stratify reflectance within each 1°X1° region by NDVI (0.1) and $\cos\theta_0$ (0.2);
- Apply modified RossLi fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each 1°X1° region.

$$\rho(\mu_0, \mu, \phi) = k_0 + k_1 \cdot B_1(\mu_0, \mu, \phi) + k_2 \cdot B_2(\mu_0, \mu, \phi)$$

from Maignan et al., 2004

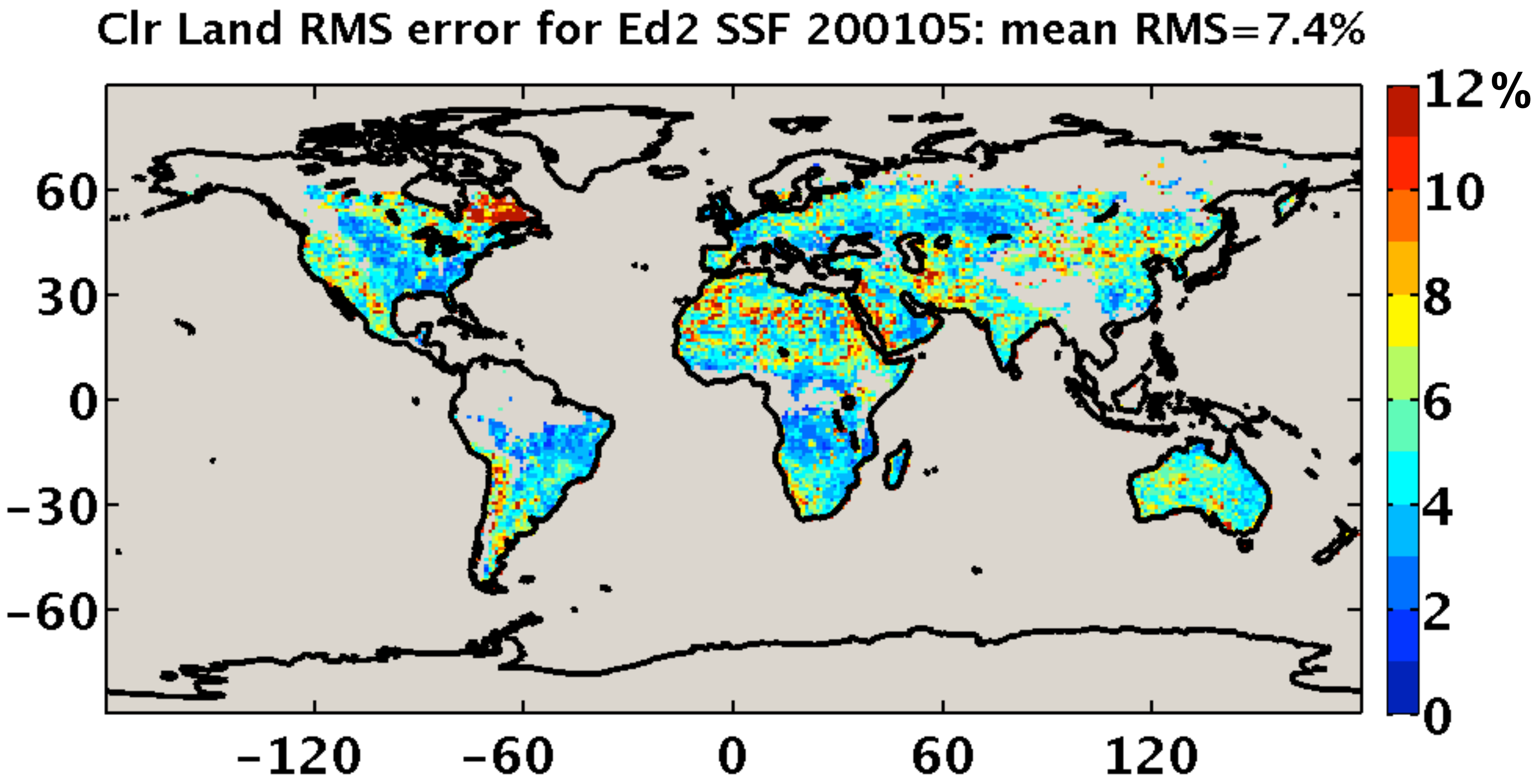


ADM for different NDVI bins



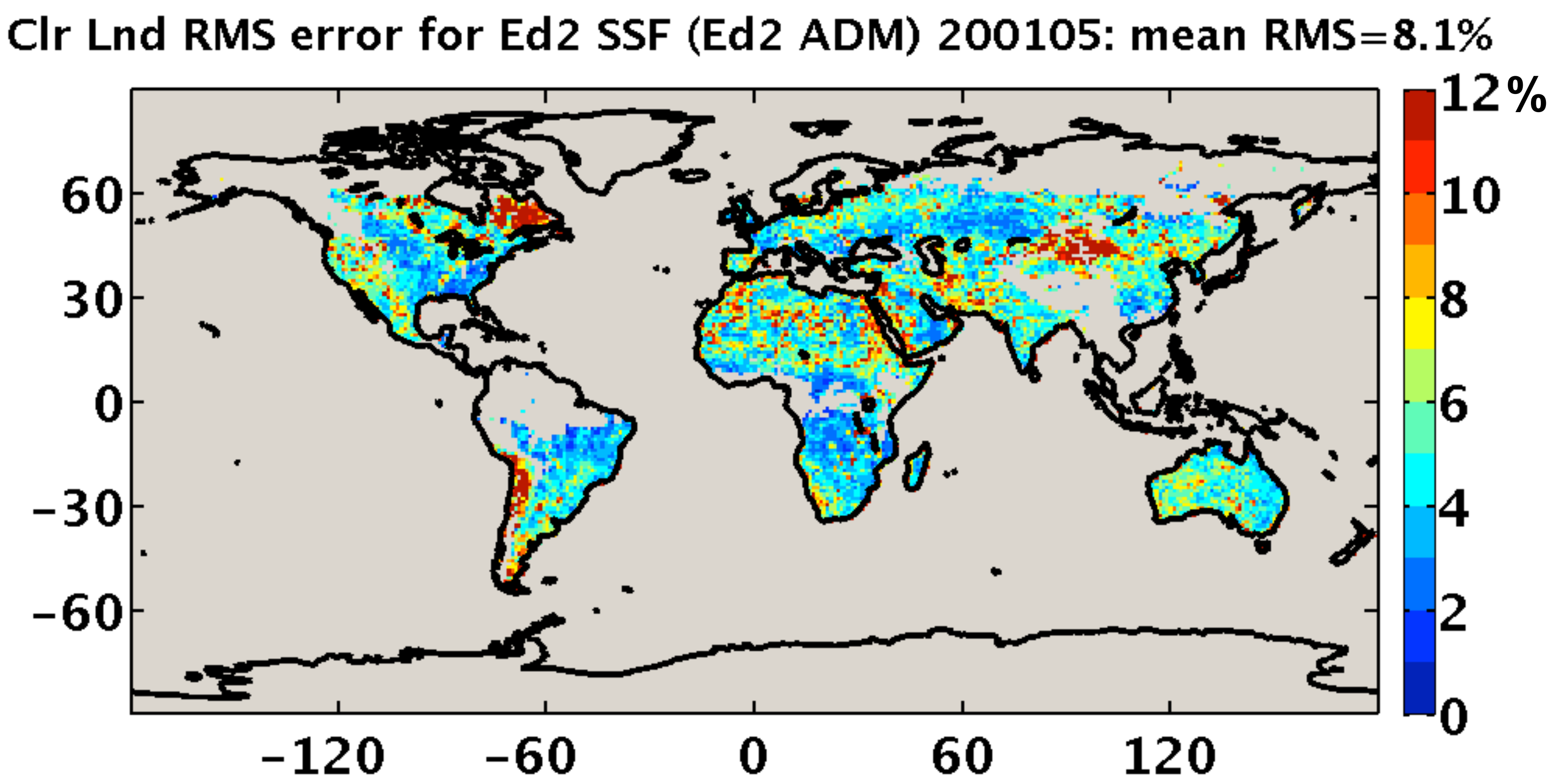
New BRDF model reduces the RMS error

- Apply prototype Ed4 ADM to Ed2 SSF



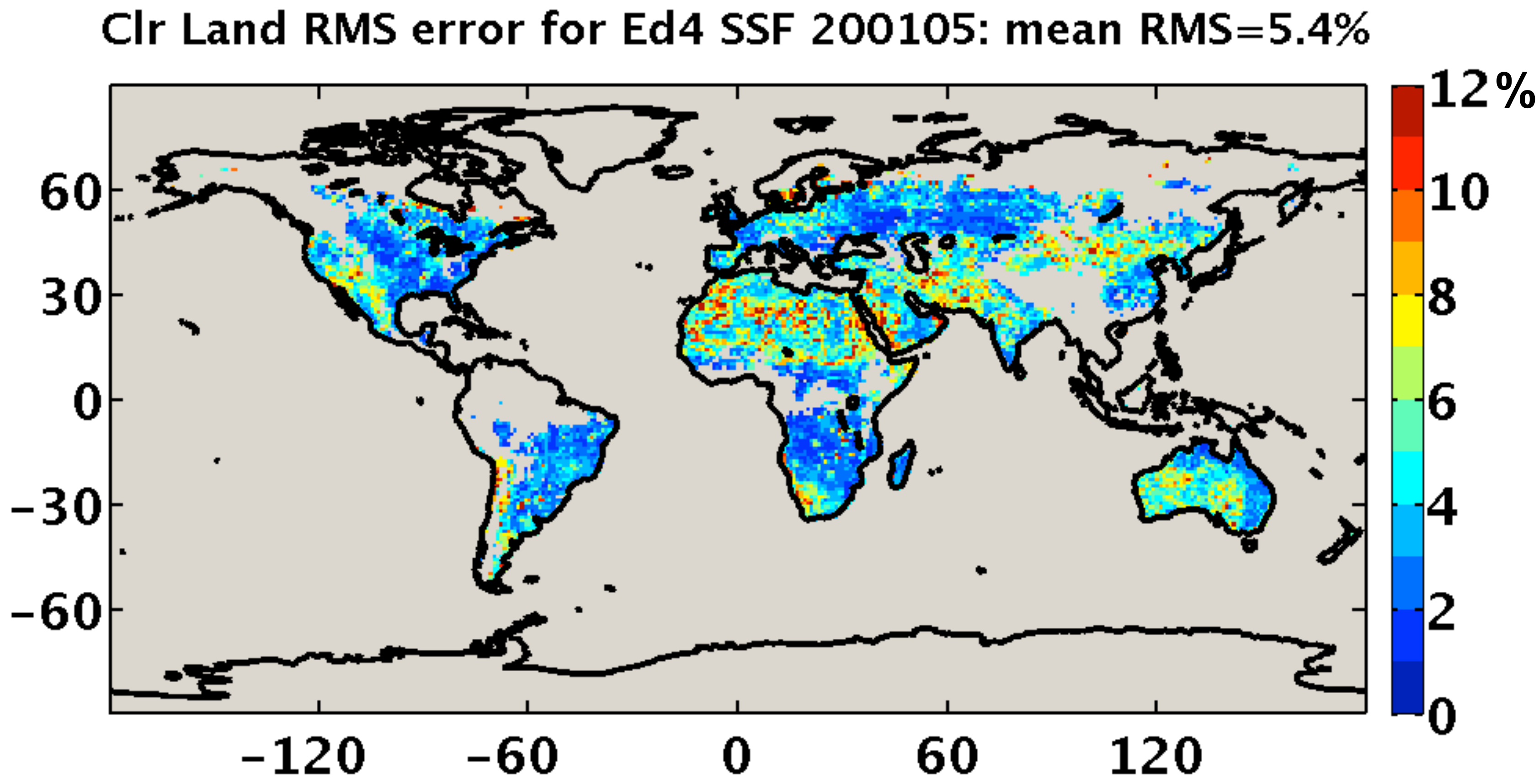
New BRDF model reduces the RMS error

- Apply Ed2 ADM to Ed2 SSF



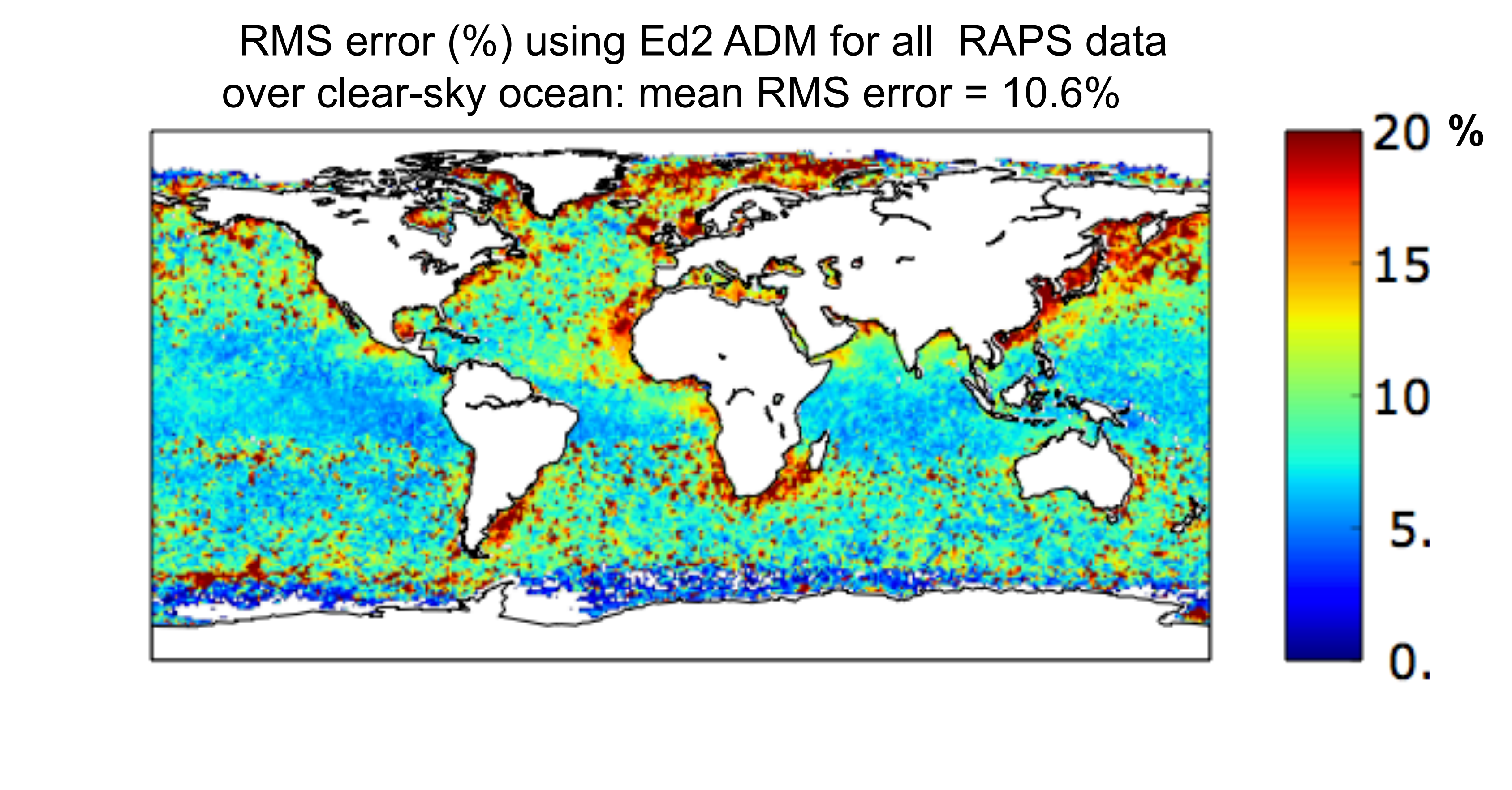
Better scene identification further reduces the RMS error

- Apply prototype Ed4 ADM to Ed4 SSF



Clear-sky angular distribution model over ocean

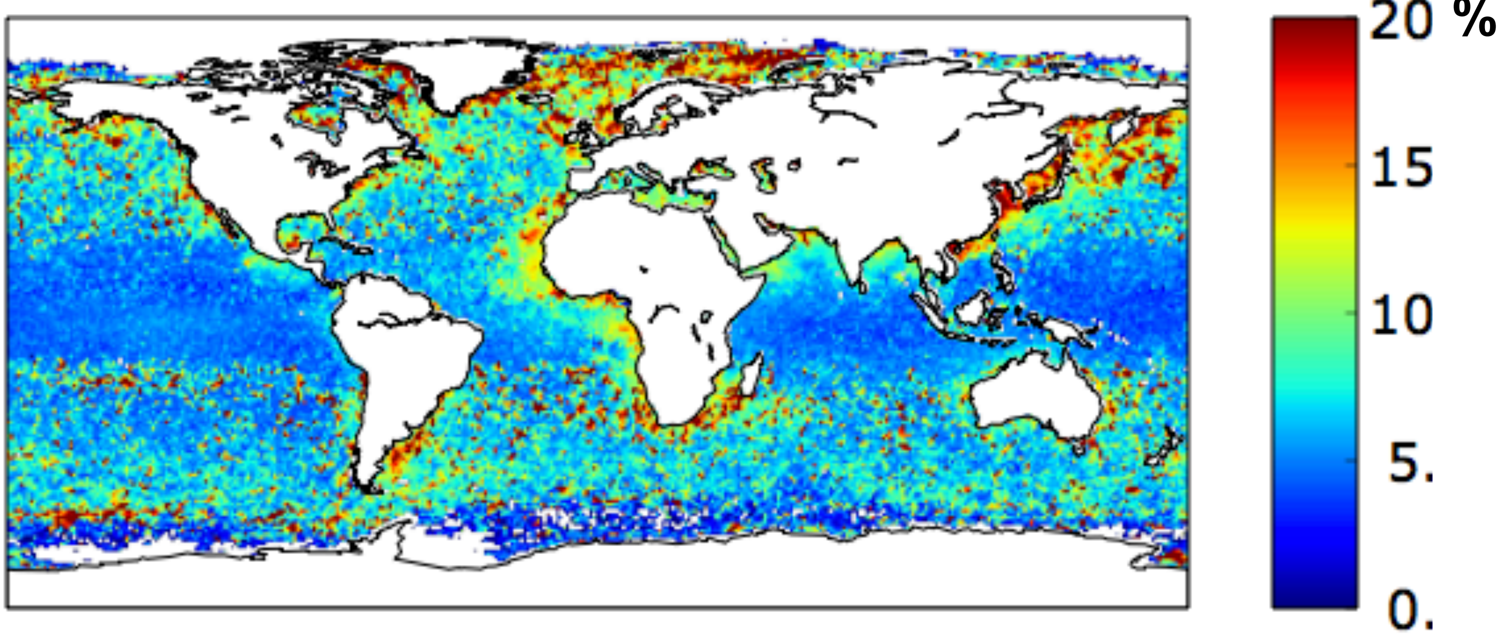
- Clear-sky ADM over ocean $R(w, \theta_0, \theta, \phi)$;
- Aerosol optical depth was not explicitly considered, ADM dependence on aerosol optical depth is implicitly accounted for by theoretical adjustment.



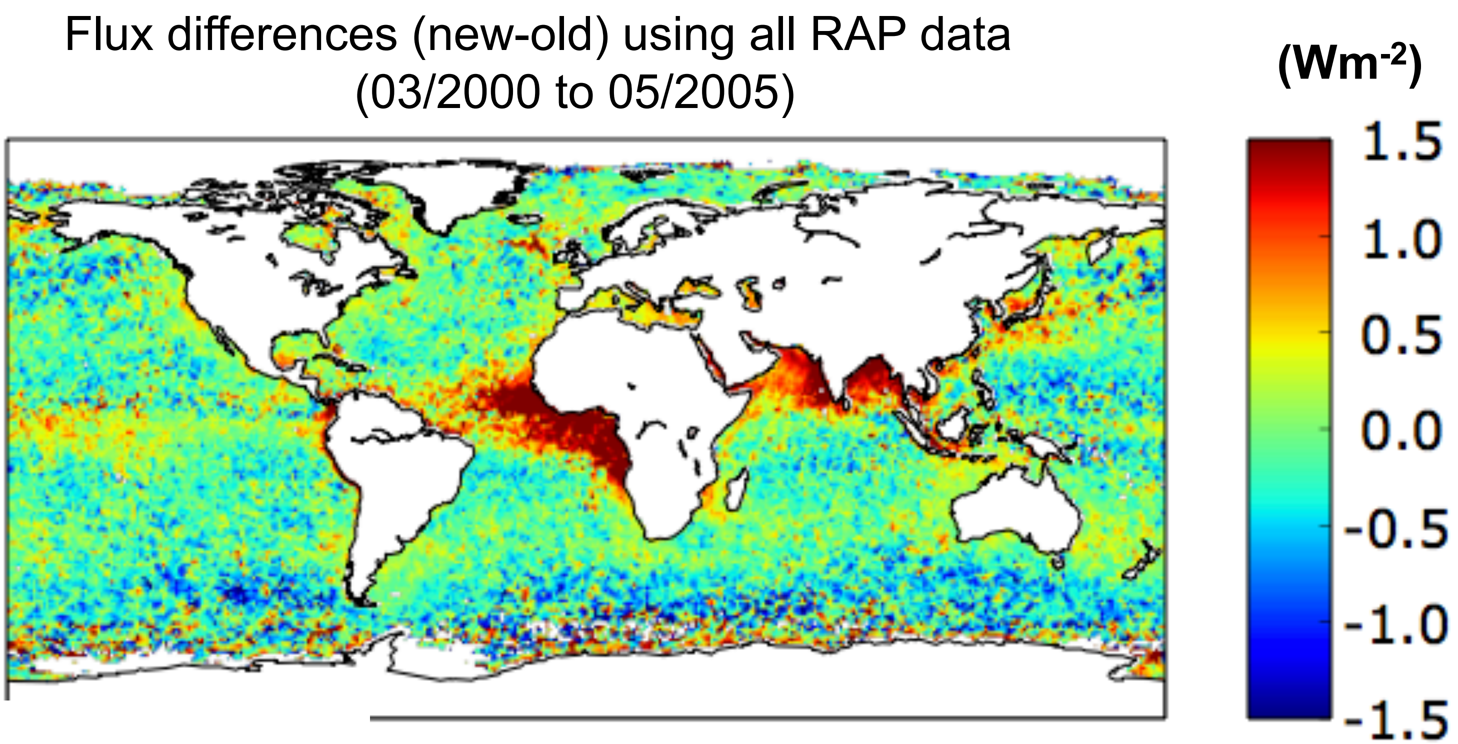
ADMs over clear ocean accounts for AOD

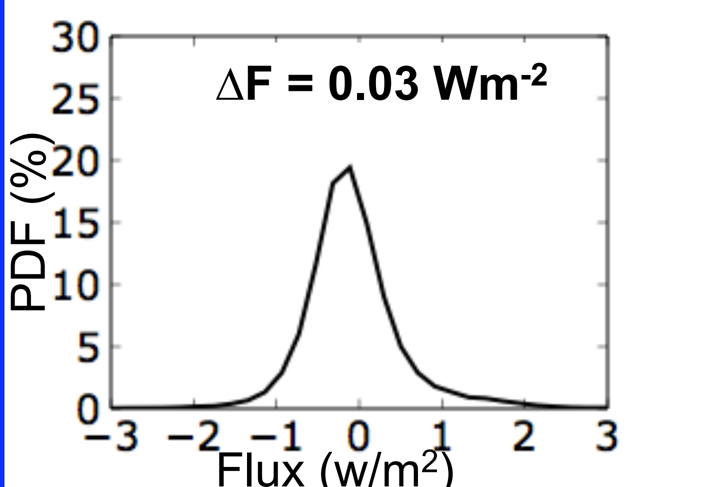
- Develop a two-band (0.64 and 0.86 μm) AOD retrieval based up maritime aerosols;
- Stratify AOD into three percentile bins;
- Build ADM for these three AOD bins separately.

RMS error (%) using AOD dependent ADM for all RAPS data over clear-sky ocean: mean RMS error = 8.6% (ΔRMS=-2.0%)



AOD dependent ADMs increase the instantaneous TOA flux around coastal regions

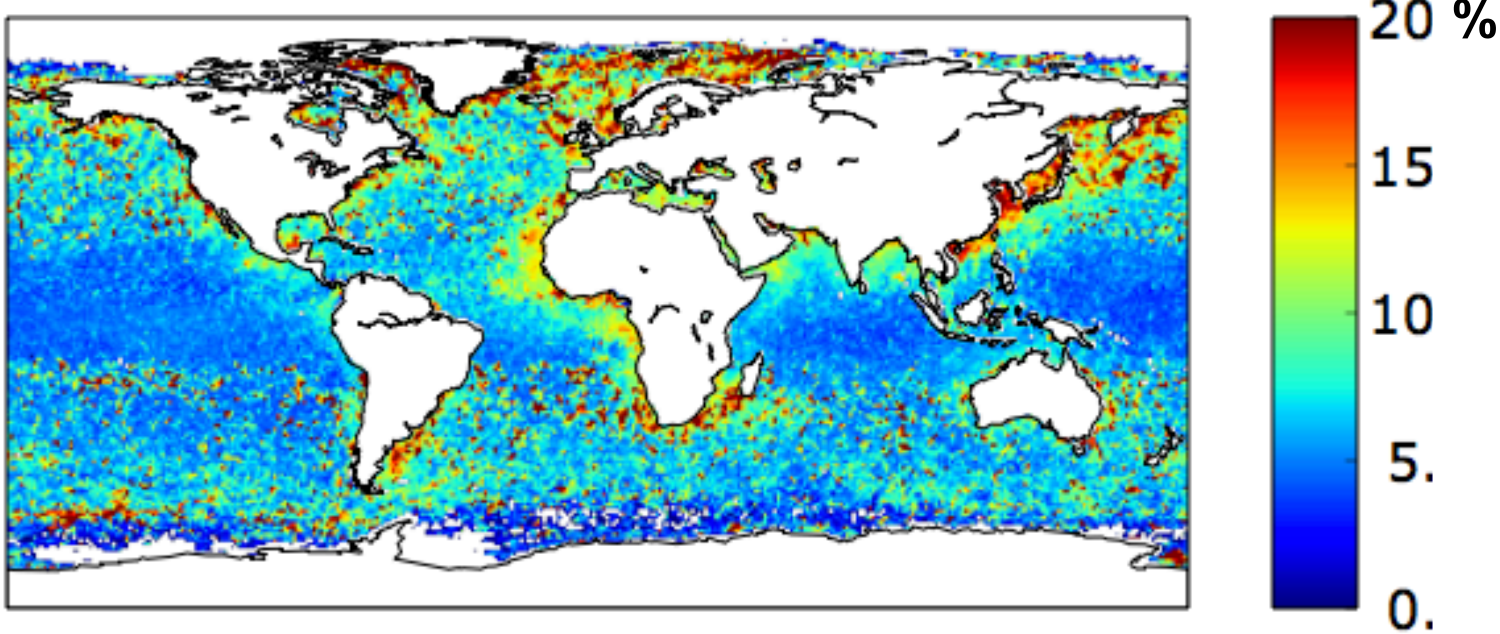




ADMs over clear ocean accounts for aerosol loading and type

- AOD retrieval based upon the fraction of fine-mode (1st MODIS aerosol model) and coarse-mode aerosol (9th MODIS model);
- Stratify fine-mode dominated AOD into 3 bins and coarse-mode dominated AOD into 3 bins;
- Build ADM for each AOD bin and type separately (6 ADMs).

RMS error (%) using AOD/type dependent ADM for all RAPS data over clear-sky ocean: mean RMS error = 8.8% (ΔRMS=-1.8%)



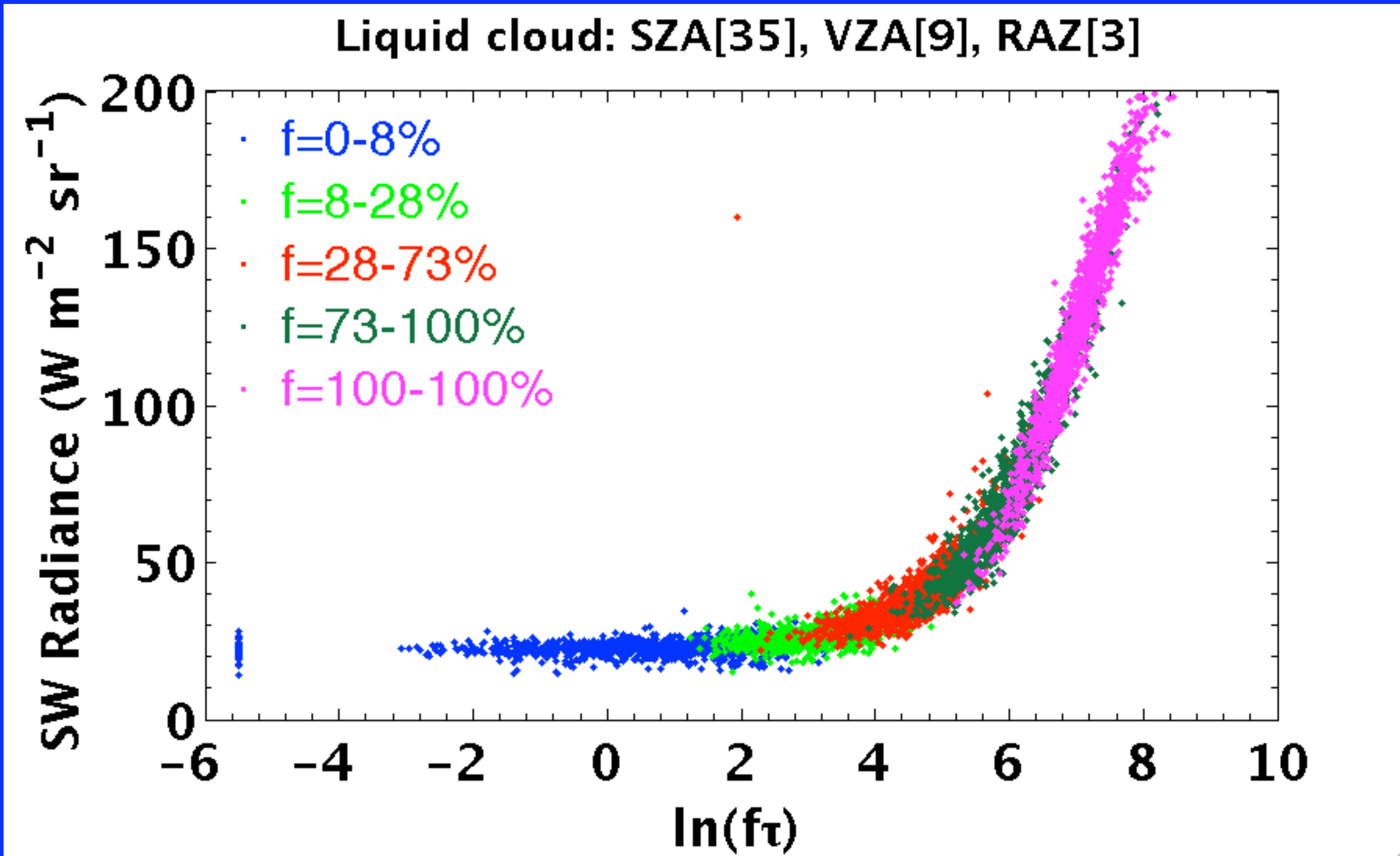
Angular distribution model over cloudy ocean

- For glint angle > 20°, or glint angle < 20° and ln(fτ) > 6:
  - Average instantaneous radiances into 750 intervals of ln(fτ), separately for liquid, mixed, and ice clouds;
  - Apply a five-parameter sigmoidal fit to mean radiance and ln(fτ);

$$I = I_0 + \frac{a}{[1 + e^{-(x - x_0)/b}]^c}$$

- For glint angle < 20° and ln(fτ) < 6:
  - Calculate mean radiance for 6 wind speed bins and 4 ln(fτ) bins;
  - Use mean radiance to build ADM

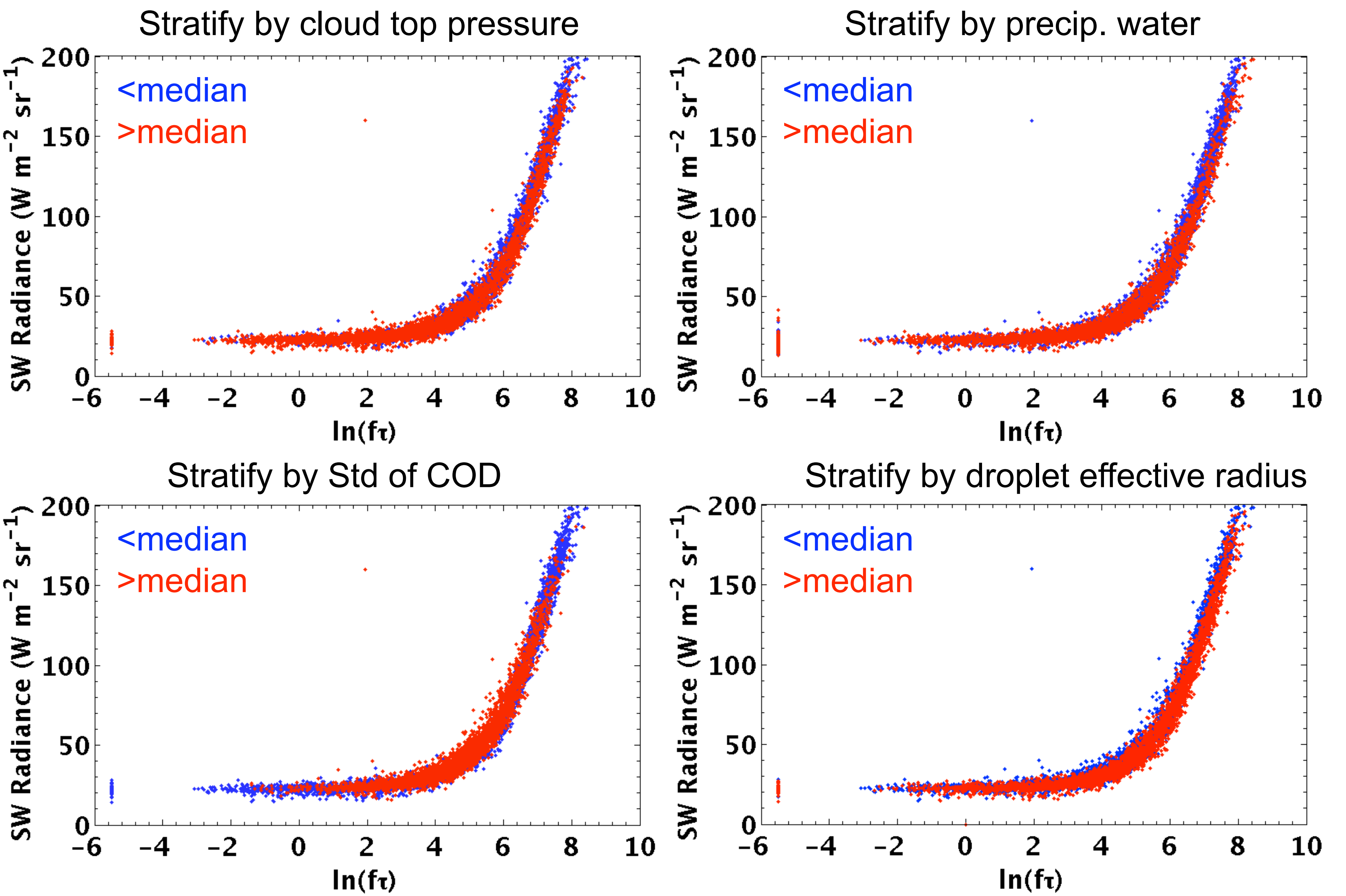
A case of sigmoidal fit over ocean: all Ed2 RAP data



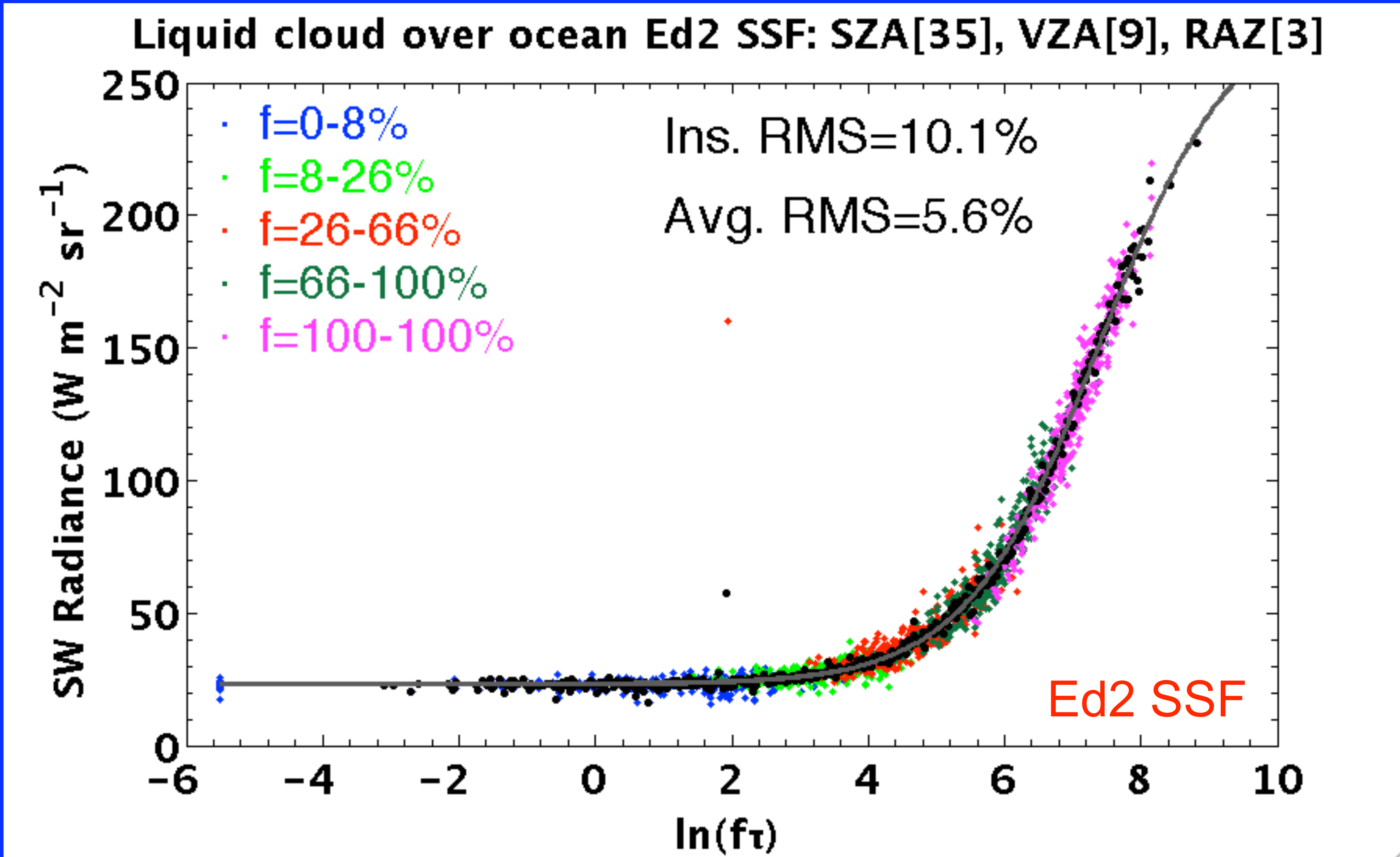
Do we need to consider other variables to define the ADM?

- Current ADM considers cloud optical depth, cloud fraction, and cloud phase;
- Are there any other variables that we need to consider?
  - Cloud top pressure
  - Cloud droplet size
  - Standard deviation of cloud optical depth
  - Precipitable water

Sigmoidal fit is not sensitive to other variables



Ed4 SSF produces tighter sigmoidal fit over ocean



Angular distribution model over cloudy land/desert

- Derive cloudy area contribution from observed radiance:

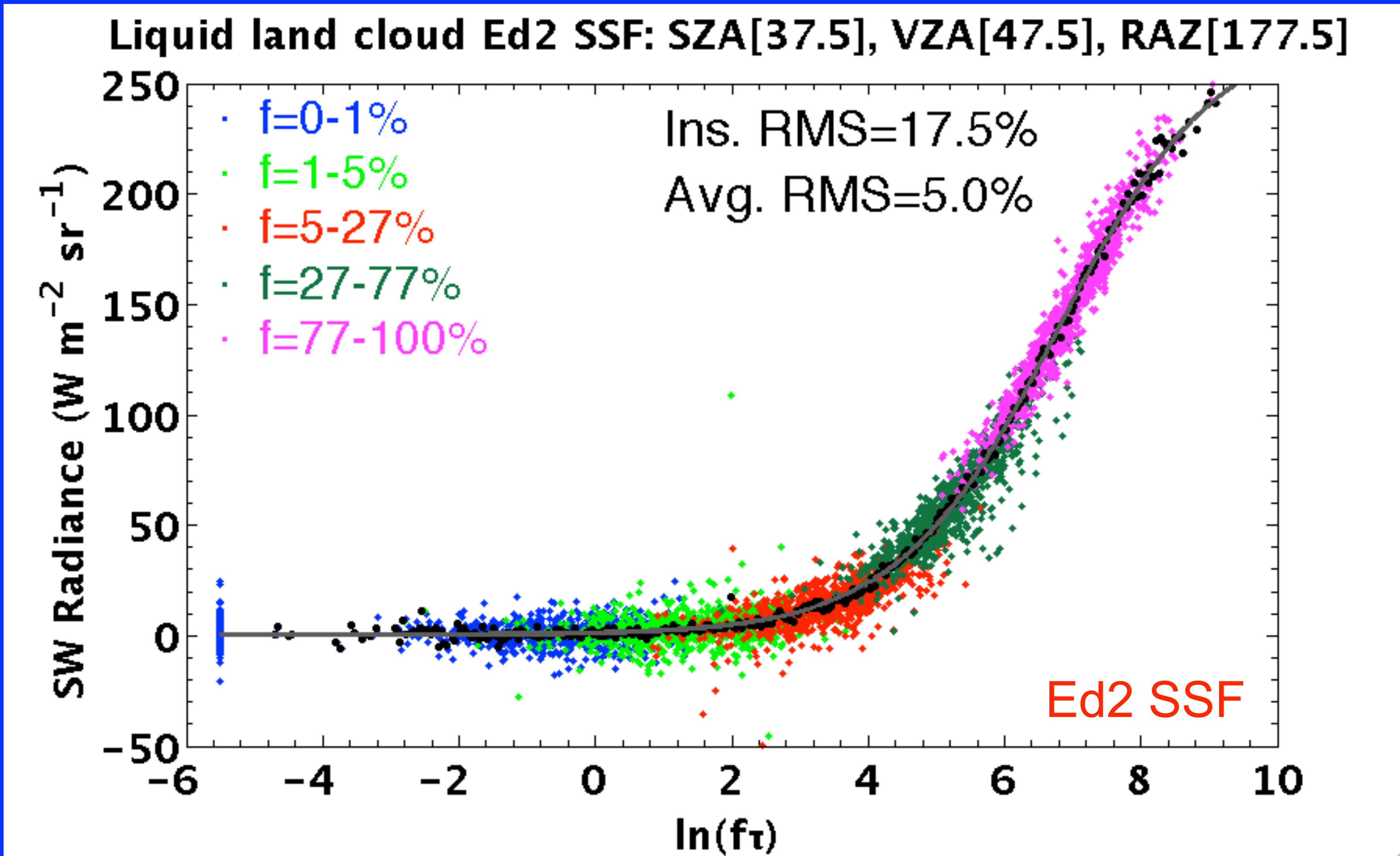
$$
\begin{aligned}
fI^{cld}(\mu_0,\mu,\phi) =& I(\mu_0,\mu,\phi) - (1-f)\frac{\mu_0 E_0}{\pi}\rho^{clr}(\mu_0,\mu,\phi) - \\
& f\frac{\mu_0 E_0}{\pi}\left[\rho^{clr}(\mu_0,\mu,\phi)e^{\frac{-\tau}{\mu_0}}e^{\frac{-\tau}{\mu}} + \overline{\alpha}^{clr}\frac{t^{cld}(\tau,\mu_0)t^{cld}(\tau,\mu)}{1-\overline{\alpha}^{clr}\overline{\alpha}^{cld}(\tau)}\right]
\end{aligned}
$$

- Average instantaneous fI^{cld} into 375 intervals of ln(fτ) for each angular bin (5°) for three cloud phases;

- Apply a five-parameter sigmoidal fit to mean fI^{cld} and ln(fτ);

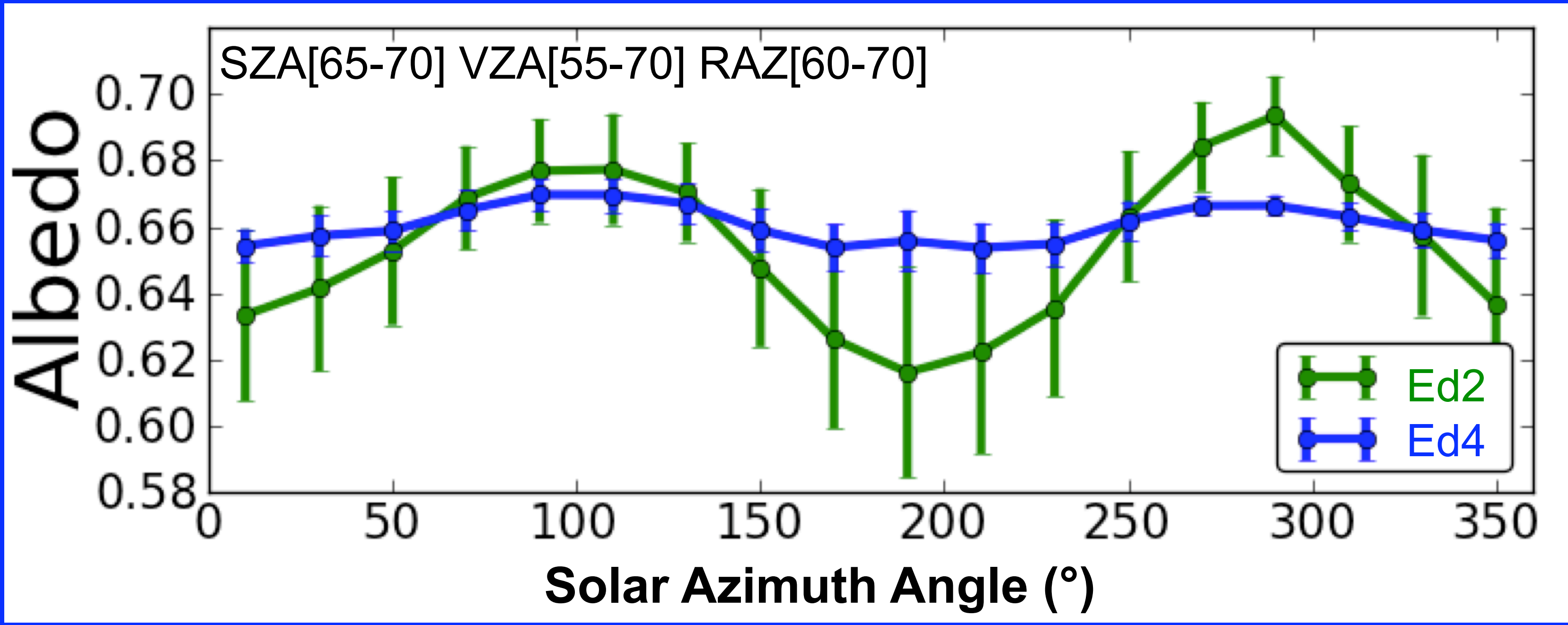
$$
I = I_0 + \frac{a}{[1+e^{-(x-x_0)/b}]^c}
$$

Ed4 SSF produces tighter sigmoidal fit over land



SW angular distribution models over snow: clear-sky

- Fresh snow:
  - Apply the RossLi fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each 1°×1° region for every seasonal month.
- Permanent snow:
  - For Antarctica, use MISR observations to correct the effect of sastrugi. The new ADMs reduce the albedo dependence on solar azimuth angle.
  - For Greenland, will evaluate after more Ed4 data becomes available

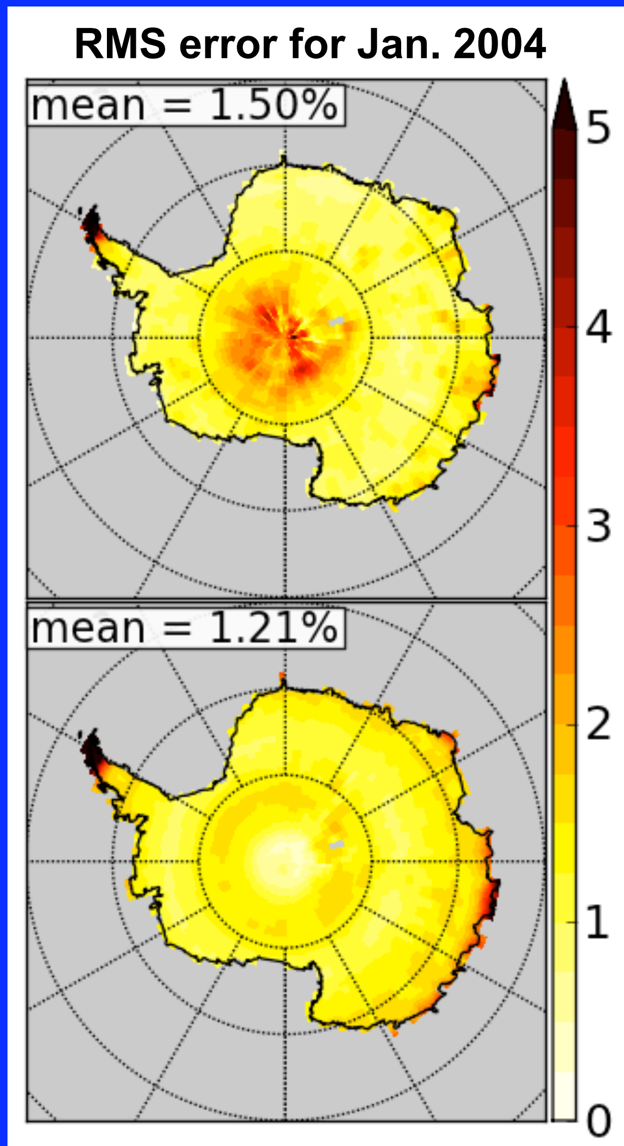


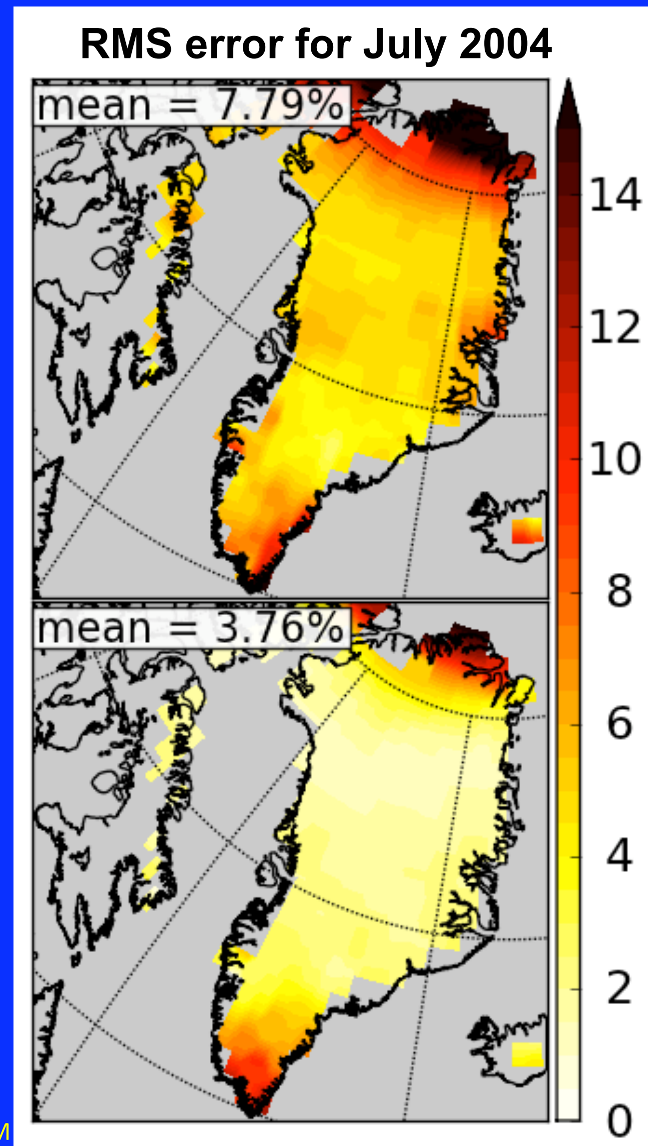
ADMs over overcast permanent snow

- Ed2: 4 ADMs based upon surface brightness and COD (≤10 and >10);
- Ed4: 4 ADMs based upon geo-location and cloud phase (<1.85 and ≥1.85);

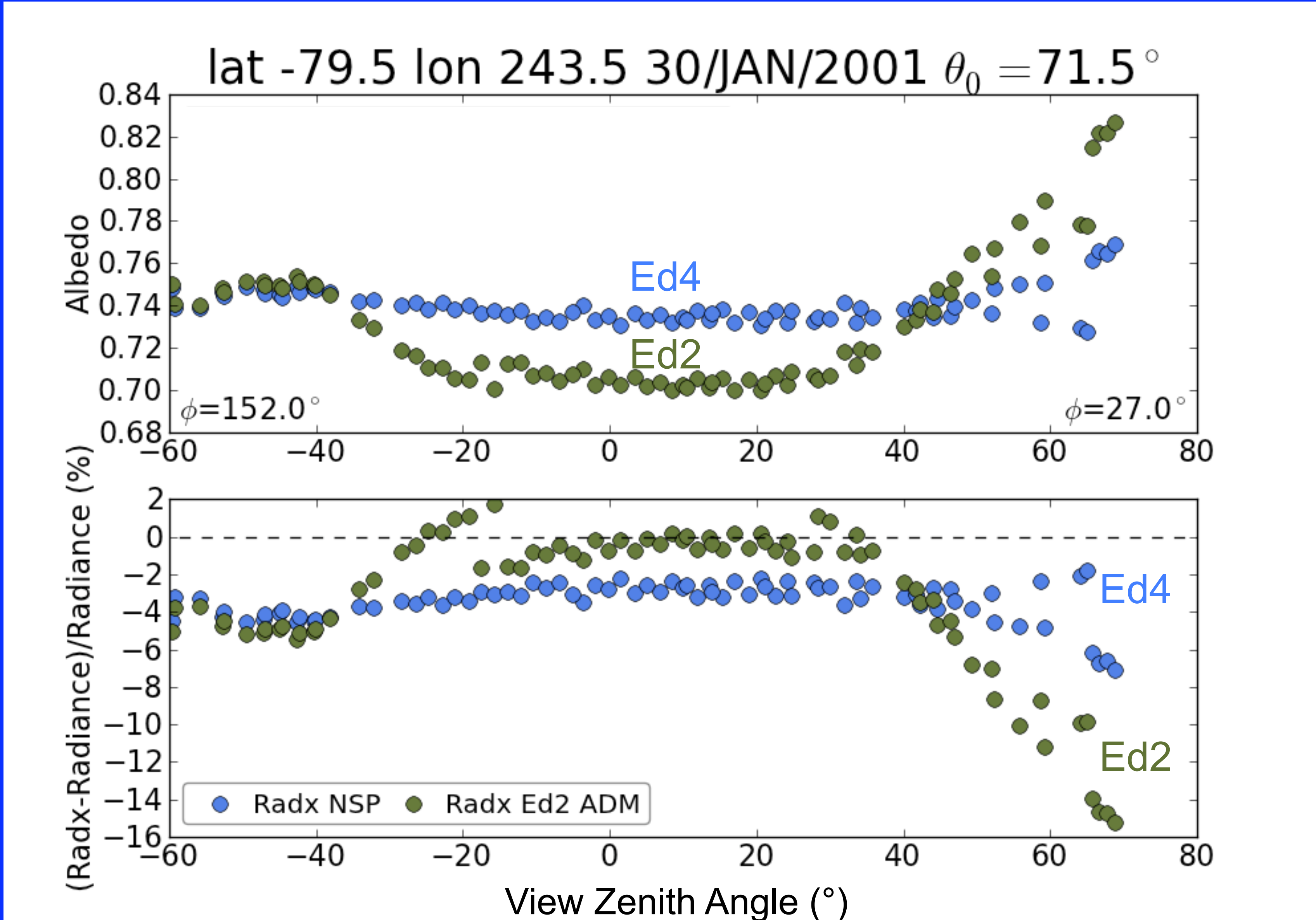
Ed2

Ed4

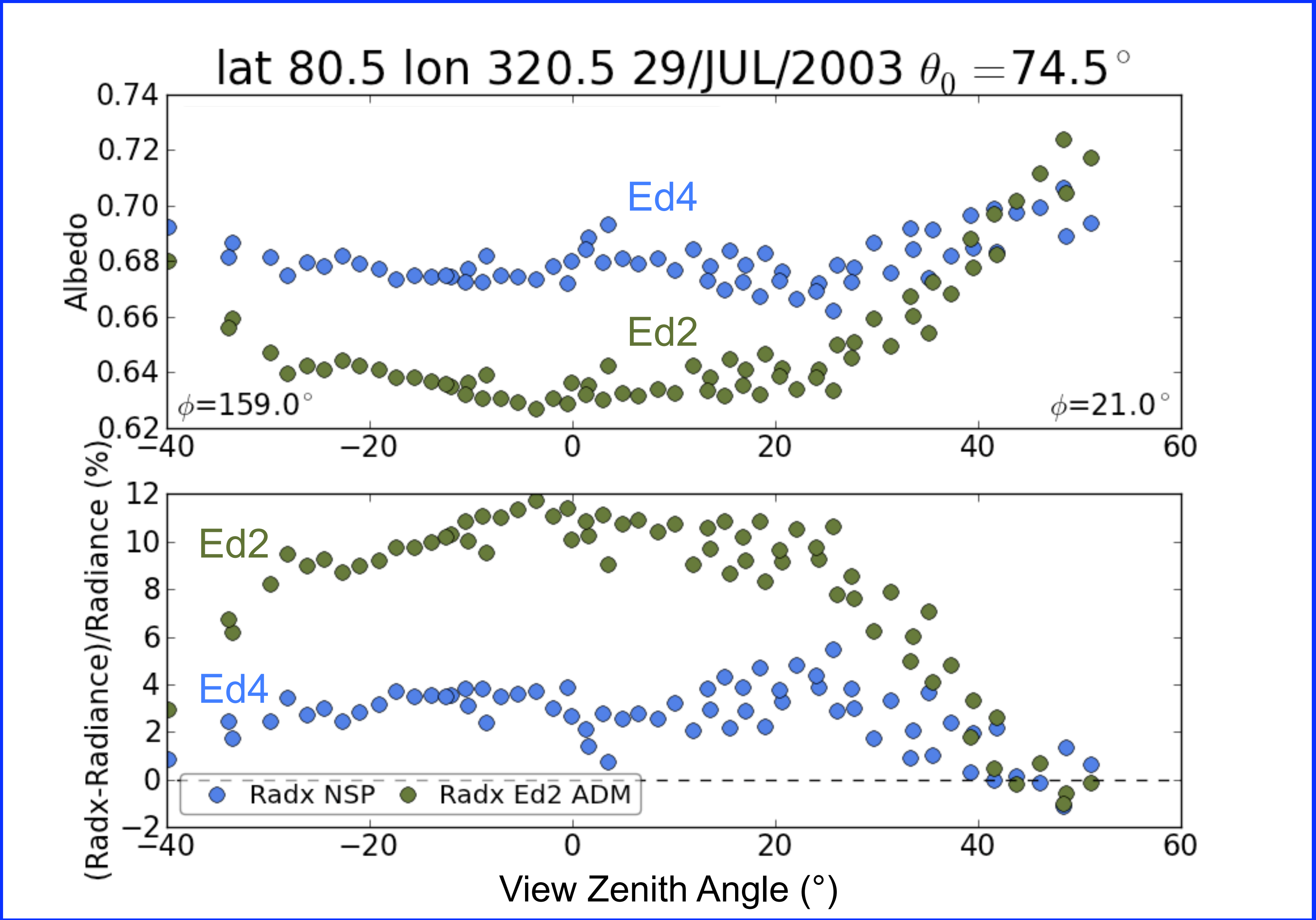




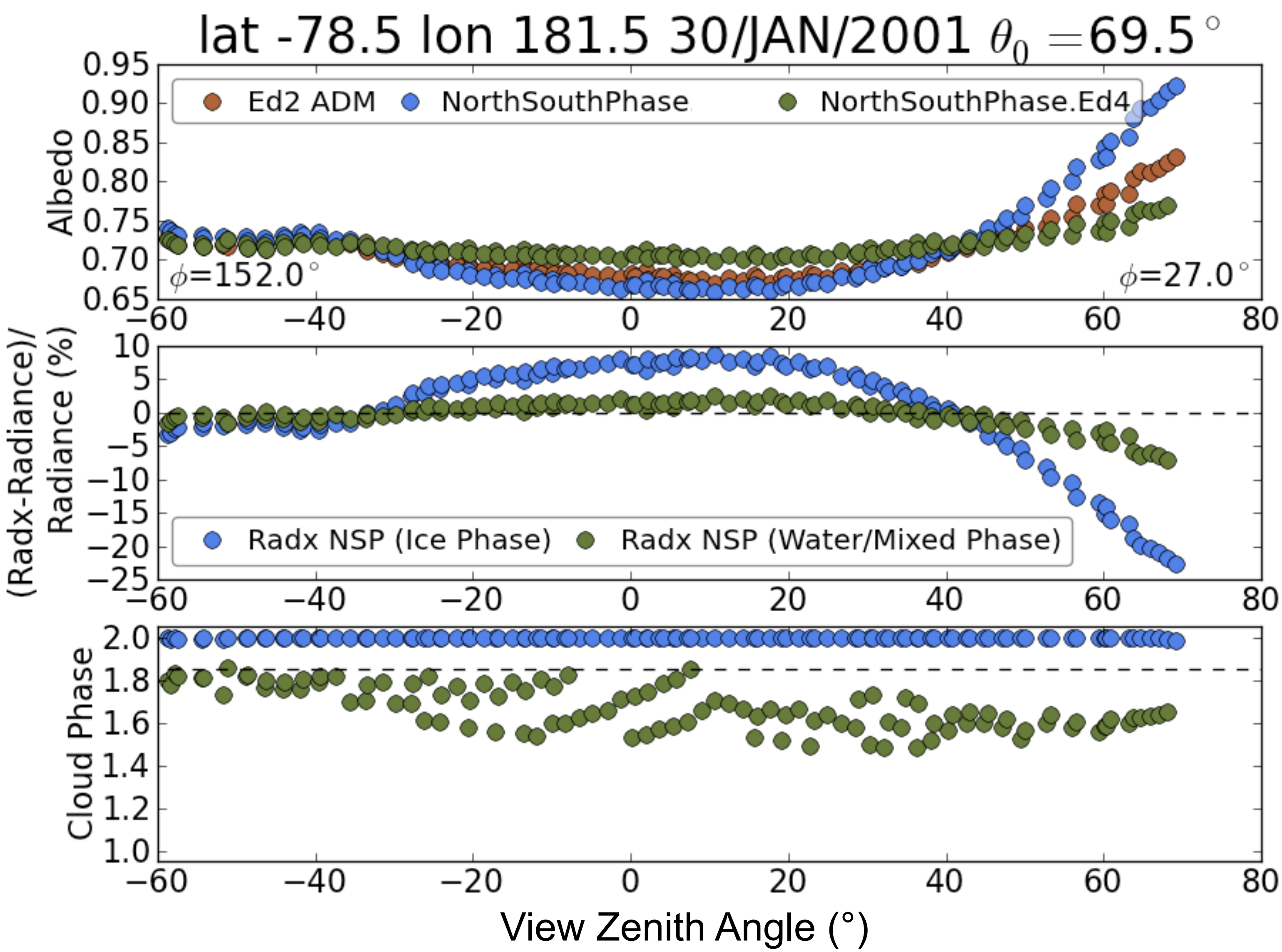
Fluxes from new ADMs show less view angle dependence over overcast permanent snow: Antarctica case



Fluxes from new ADMs show less view angle dependence over overcast permanent snow: Greenland case



Effect of Ed4 cloud property change

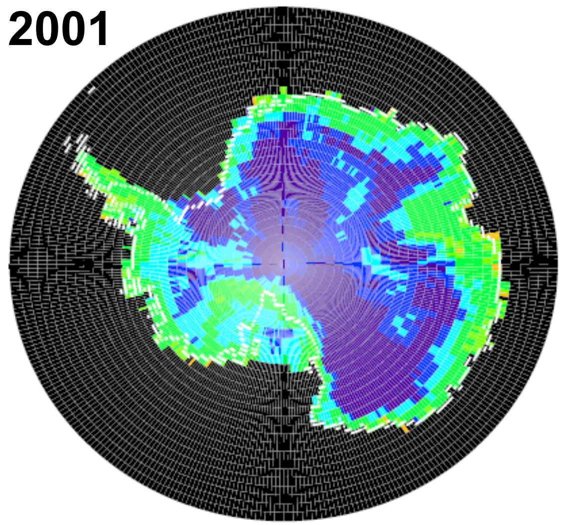


LW angular distribution models over different scenes

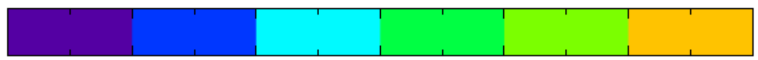
- Over clear land/ocean/snow/ice:
  - Add surface skin temperature (Ts) bins and interpolation between the Ts bins;
- Over cloudy land/ocean:
  - Replace the third-order polynomial fits between radiance and 'pseudoradiance' with interpolation;
  - Will evaluate if more bins are needed;
- Over cloudy snow/ice:
  - Add more Ts bins and interpolation between the Ts bins, also add one more surface-cloud temperature difference (ΔTsc) bins;
  - Will evaluate if we can adopt the 'pseudoradiance' method over snow/ice scenes.

Large changes in Terra polar night cloud mask (Ed4-Ed2)

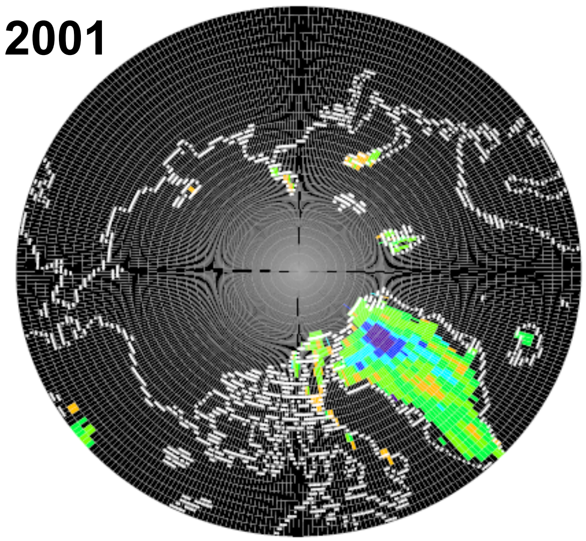
July 2001



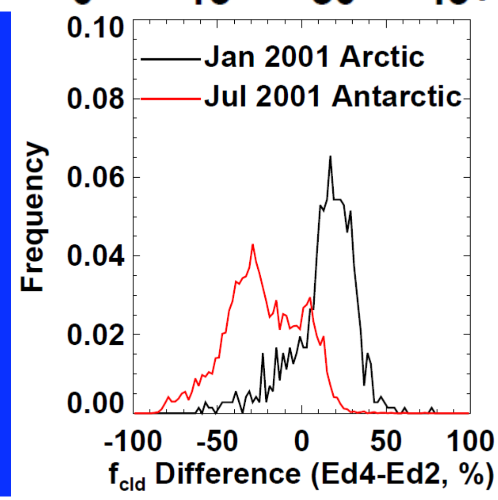
Avg Δf_{cld} = -22.7%



Jan. 2001

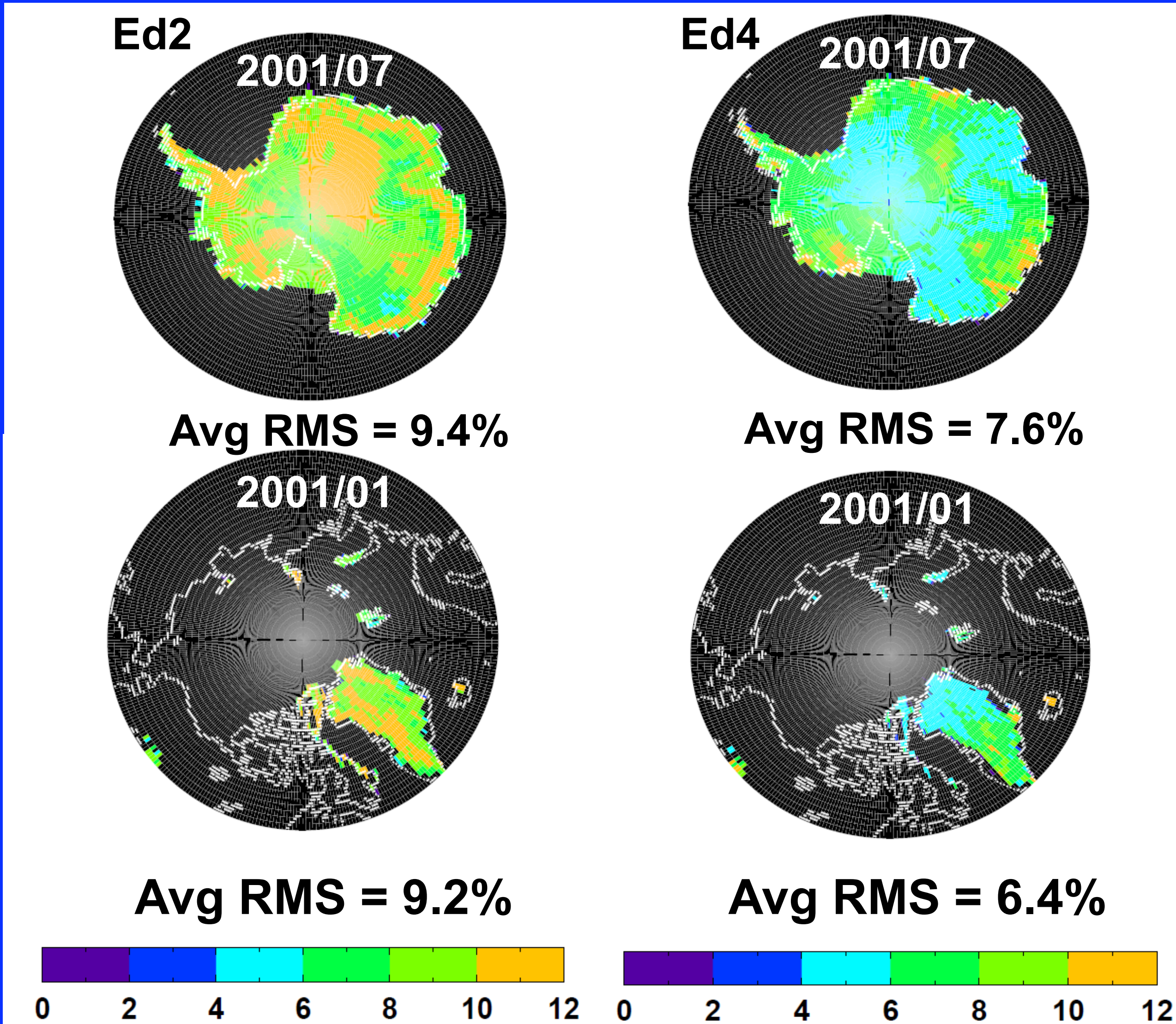


Avg Δf_{cld} = 13.3%



Ed4 LW ADMs over nighttime permanent snow reduces the RMS error

- Use one year of Ed4 SSF data to develop the preliminary Ed4 ADM
- Use same one year of Ed2 SSF data to develop the Ed2 ADM
- Both use the updated the Ts and ΔTsc bins



Status

- We have worked through most scene types and have seen some improvement in the proposed Ed4 ADMs
- Initial evaluation indicates that improved cloud algorithm in Ed4 SSF will also improve Ed4 ADMs
- We will assess the possibility of combined Terra/Aqua ADMs
- Deliver Edition 4 ADM in Oct. 2013